EFFECT OF CONSTRUCTING HIGH-RISE BUILDINGS WITHOUT A GEOPHYSICAL SURVEY

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Abstract

Subsidence and building collapse has become immense globally which Nigeria is not exempted. Due to increase in the number of people living in urban area and increase in the value of land, high-rise buildings have become preferred choice for people. Some of the high-rise buildings in urban areas have become death traps for the people living within because of cracks, subsidence, transport of water from subsurface to the supporting walls of the building, and finally sudden collapse. People direct the blame on the contractor whenever there are tragic situations like that. Majority believes that the contractor must have used inferior building materials before there can be such situation. The truth is that subsurface is heterogeneous in nature, if proper geophysical survey is not carried out before the building construction starts, the constructed building especially high-rise building might stand the chance of falling into this tragic event. The aim of carrying out this research is to settle the dispute between a house owner along Oda Road, Akure, Ondo State, Nigeria and his contractor. Vivid cracks were seen from a high-rise building after the construction works have finished which made the owner to believe that the contractor has used the inferior building materials for him. Eight Vertical Electrical Sounding (VES) stations were occupied around the house in order to know the subsurface information of the study area. The maximum current electrode used was 300 m with the maximum Geometric Factor of 7069.58. Six VES curves showed H-type (i.e. 3-layer earth model) while the remaining two VES curves showed KH-type (i.e. 4-layer earth model). The overburden thickness information of the study area varied between 14.9 m and 39.6 m with an average value of 28.3 m. This overburden is relatively thick for a high-rise building without an artificial basement before the foundation is laid. The weathered layer isoresistivity varied between 102.8 Ωm and 258 Ωm with an average value of 160.4125 Ωm. This was done in order to know the characteristics of weathered layer in the study area, whether it will permit the transport of water from subsurface to the supporting walls of the building or not. The result showed that the apparent resistivities of the weathered layer's value constitute little and medium weathering processes with poor potential for groundwater. Therefore, water cannot be transported from the subsurface to the supporting walls of the building. The contractor has his blame because geophysicist should have been invited for geophysical survey before the construction works started. Finally, it was recommended that mega activities like party, playing of heavy acoustic music, manual pounding of yams within the building, use of heavily vibrated machines should be avoided in the building.

Keywords: *Building Collapse, Building Construction, Geophysical Survey, Overburden Thickness, Subsidence, Vertical Electrical Sounding*

Introduction

In geophysics, the Earth's crust is filled with fractures on a range of scales from centimeters to thousands of kilometers. The term *fracture* covers both joints and faults. If no lateral displacement has occurred across a fracture, it is classified as a joint; if a lateral displacement has occurred, it is classified as a fault. Whatever the type of structure, the qualities of the subsoil must be investigated either by geophysical survey alone or in conjunction with geotechnical survey. Buildings are expected to have certain characteristics that make them attractive for many uses which may be residential, commercial, institutional, educational, and industrial to meet people's daily needs. Characteristics of a good building include provision of security, safety to lives and properties, convenience, in addition to social, psychological and economic satisfactions derived by occupiers. In some cases, buildings that are expected to meet the people's daily needs have become source of great concerns to occupiers, owners, developers, governments, and physical development planning authorities, consequent upon their incessant failure and collapses (Adagunodo et al., 2013).

Causes of foundation failure include: faulty or no subsurface investigation, wrong choice or wrong design of suitable foundation, and sinking of column footings. The frequency of collapse of building structures in Nigeria in the past few years had become very alarming and worrisome. Many lives and properties have been lost in the collapse of buildings mostly in Port Harcourt, Abuja and Lagos. Many property owners have developed high blood pressure and some have been sent to an early grave. One fundamental principle of building design is that a building should be designed and constructed to meet its owner’s requirements and also satisfy public health, welfare and safety requirement. No part of such building should pose a hazard to its occupants (Fredrick et al., 1989). Substandard material especially reinforcement rods, steel sections and cement can contribute immensely to failure of buildings. Some of these contractors are faithful to their clients but at the end of the day, the fact that they (contractors) have neglected the geophysical survey in order to understand the subsurface features, their effort went uncrowned with series of complains that arise after the construction of the building which finally leads to the collapse of the constructed building. Table 1 gives account of randomly selected buildings that were collapsed and the numbers of live lost or injured in the past three decades across Nigeria.

The alarming rate of structural failure such as roads, buildings, dam and bridges in Nigeria has become more intense. The need for pre-foundation studies can therefore not be overemphasized as it may constitute a significant potential hazard to the downstream people such as loss of valuable lives and properties that always accompany such failure (Akanmu et al., 2007; Oladunjoye et al., 2013). The basement mapping and geophysical foundation study usually provides subsurface information that assists the construction engineers in location of the right site and design of foundation for different structures. There are series of geophysical methods such as electrical, gravity, electromagnetic, magnetics, seismic and radiometry, that responds to physical properties of the subsurface media which could be used singly or in combinations for subsurface sequence and structure disposition site investigation. In this research paper, a post-foundation survey was done around a storey building along Oda road, Akure, Ondo State, Nigeria because the contractor failed to carry out the pre-foundation survey before the construction started. Vivid cracks were seen from a high-rise building after the construction works have finished which made the owner to believe that the contractor has used the inferior building materials for him. Eight Vertical Electrical Sounding (VES) or ‘Electric Drilling’ (Koefoed, 1979; Ogungbe, 2013) stations were occupied around the house in order to know the subsurface information of the study area. The Schlumberger array is mostly used for VES surveys because of its logistic simplicity (Sunmonu et al., 2012) and that is the reason why Schlumberger array has been employed in this research. This method has been employed by Adelusi et al. (2009), Fatoba et al. (2010), Adagunodo and Sunmonu (2012), Sunmonu et al. (2013a), and Sunmonu et al. (2013b).

The Study Area

The study area is located along Oda road, about 3 Km from Alagbaka GRA, the location of the Government house and all other major administrative buildings in Akure, the Ondo State Capital. It’s also located on a rugged and gentle undulating terrain characterized by outcrop of granite and charnokite rocks. The climate of the area comprises short dry season and long wet season. The wet season last from April to November with a peak in June and July. These are vindicated by dense evergreen forest vegetation. The dry season last from November to March with December and January being the driest months. The temperature varies between 25^0 C and 30^0 C throughout the year with high humidity during the wet season and low humidity during the dry season (Iloeje, 1972; 1980).

The study area is underlain by Precambrian Basement Complex which falls within the Southwestern portion of Nigeria Precambrian basement complex (figure 1) (Adepelumi and Fayemi, 2012) which lie within Pan African mobile belt, East of West African Craton. The basement complex is believed to be polycyclic (Rahaman, 1976). Locally, the study area is underlain by basement rock types such as slightly migmatite gneiss complex rocks that are slightly migmatised to non-migmatite metasedimentary and meta-igneous rocks, charnokites and granite rocks, it is also bounded by latitude $7^0\ 18^{\prime}\ 16.21^{\prime\prime}$ North and longitude $5^0\ 19^{\prime}\ 09.02^{\prime\prime}$ East.

Materials and Methods

The electrical resistivity method utilized the vertical electrical sounding (VES) method involving the Schlumberger array. Eight Vertical Electrical Sounding (VES) stations were occupied around the house in order to know the subsurface information of the study area. The maximum current electrode used was 300 m with the maximum Geometric Factor of 7069.58. The apparent resistivity measurements were plotted against electrode spacing on bi-logarithmic graph sheets. Partial curve matching was carried out using WinGLink software for the quantitative interpretation of the sounding curves. The results of the curve matching (layer resistivities and thickness) were used as starting model parameters for 1-D forward modeling using a computer iterating software WinResist to check RMS-error in order to make sure that the VES stations were averagely 98% error free. The VES interpretations were used for the construction of geoelectric sections along the various segments, construction of overburden thickness maps, and weathered layer isoresistivity maps in order to check the subsurface competency for the high-rise building construction. The study area, the VES locations, and the cracks that were seen on the walls of the building were presented from figure 2a to figure 2c.

Result and Discussion

The resistivity sounding curves of the 8 VES stations (figure 3) obtained from the survey area consist of three and four geoelectric layers. Six VES curves (VES 1, 2, 4, 5, 6, and 8) showed H-type (i.e. 3-layer earth model) while the remaining two VES curves (VES 3 and 7) showed KH-type (i.e. 4-layer earth model). The curves were characterized according to their signatures, which mirror the layering of the subsurface. The resistivity of the topsoil ranged between 272.8 Ωm and 622.2 Ωm with an average value of 374.5 Ωm, the thickness of the topsoil ranged between 1.1 m and 3.0 m with an average value of 1.7625 m, the resistivity of the weathered layer ranged between 102.8 Ωm and 258 Ωm with an average value of 160.4125 Ωm, the thickness of the weathered layer ranged between 13.8 m and 37.6 m with an average value of 25.875 m, the overburden thickness of the survey area ranged between 14.9 m and 39.6 m with an average value of 28.3 m. Summary of the formation of layer parameters and classification of the resistivity sounding curves are presented in Table 2 and 3.

Overburden thickness interpretation with respect to subsurface competency for the construction of high-rise building in the study area is as follow: figure 4 shows that only the Southern part of the building is underlain with thin overburden while the remaining parts are relatively thick. According to Sunmonu et al. (2012), who rated overburden greater than 15 m (about 50 ft) as thick (table 4), it could be seen from figure 5 that except VES 6 that has the value of 14.9 m (approx. 15 m), other VES stations are greater than 15 m. This overburden is relatively thick for a high-rise building without an artificial basement before the foundation is laid.

However, the weathered layer isoresistivity interpretation with respect to subsurface competency for the construction of high-rise building in the study area is as follow: the resistivity varied between 102.8 Ωm and 258 Ωm with an average value of 160.4125 Ωm. The 3-D weathered layer isoresistivity map (figure 6) was produced from the interpreted VES data. Also, the distribution of the weathered layer isoresistivity was produced in figure 7. From figure 6 and figure 7, none of the weathered layer resistivity falls within the zone of optimum weathering and good groundwater potential i.e. resistivity ranging from 21 Ωm and 100 Ωm. The closest resistivities are that of VES 5 and VES 6 which are 103.4 Ωm and 102.8 Ωm respectively. These 2 VES stations fall under the medium conditions and medium potential for groundwater as reported by Sunmonu et al. (2012). This was done in order to know the characteristics of weathered layer in the study area, whether it will permit the transport of water from subsurface to the supporting walls of the building or not. The result showed that the resistivities of the weathered layer's value constitute little and medium weathering processes with poor potential for groundwater (table 5). Therefore, water cannot be transported from the subsurface to the supporting walls of the building.

Table 1: List of collapse buildings' record in the last three decades (after Dimuna, 2010).

Dates of Incident	States	Types of Buildings	No of lives Lost or Injured
Dec., 1976	Ondo	1 Storey	8 Died
June, 1977	Oyo	2 Storey	10 Died
June, 1977	Kaduna	School Building	16 Died (Several Injured)
Oct., 1977	Borno	4 Storey	10 Died
March, 1978	Rivers	4 Storey	16 Died
March, 1982	Lagos	3 Storey	10 Died
June, 1982	Lagos	2 Storey	7 Died
June, 1982	Ondo	2 Storey	7 Died
Sept., 1983	Lagos	2 Storey	8 Died
Dec., 1983	Lagos	4 Blocks of flats	6 Died
May, 1985	Lagos	-	9 Died
June, 1985	Lagos	2 Storey	5 Died
July, 1985	Lagos	3 Storey	9 Died
Nov., 1986	Lagos	-	1 Died
May, 1987	Lagos	2 Storey	4 Died
Sept., 1987	Lagos	3 Storey	8 Died
Nov., 1988	Lagos	School Building	1 Died (Others Injured)
Feb., 1989	Lagos	-	-
June, 1990	Rivers	School Building	50 died (Several Injured)
July, 1991	Kano	1 Storey	3 Died
July, 1991	Sokoto	1 Storey	4 Died
August, 1991	Lagos	2 Storey	10 Died
March, 1992	Lagos	3 Storey	10 Died
June, 1992	Lagos	Hotel Building	2 Died (Several Injured)
Oct., 1993	Kano	1 Storey	5 Died
March, 1994	Oyo	2 Storey	4 Died (11 Injured)
June, 1994	Lagos	3 Storey	17 Injured
June, 1994	Lagos	Uncompleted 4 Storey Building	1 Died
Aug., 1994	Kwara	1 Storey	2 Died (6 Injured)
Aug., 1994	Oyo	2 Storey	10 Died (74 Injured)
June, 1994	Lagos	4 Storey	4 Died (Several Injured)
Aug., 1994	Ondo	1 Storey	1 Died (Several Injured)
Jan., 1995	Lagos	6 Storey	1 Died
May, 1996	Lagos	Uncompleted Church Building	3 Died
Oct., 2004	Umuahia	3 Storey Building	4 Died (Many Injured)
May, 2005	Iludun, Ogun State	4 Storey Building	10 Died (Many Injured)
June, 2005	Aba	4 Storey Building	25 Died (Many Injured)
June, 2005	Lagos	3 Storey Building	20 Died (Many Injured)
July, 2005	Port-Harcourt	4 Storey Building	25 Died (Many Injured)
July, 2005	Port-Harcourt	5 Storey Office Building	30 Died (Many Injured)
July, 2005	Lagos	3 Storey	30 Died (Many Injured)
August, 2005	Adamawa	Collapse of Bridge	45 Died (Many Injured)
August, 2006	Oworonshoki, Lagos	2 Storey Building	4 Died (Many Injured)
August, 2006	Lagos	4 Storey Building	50 Died (Many Injured)
2010	Akure	1 Storey	-
Sept. 27, 2013	Abuja	1 Storey	6 Injured
July 10, 2014	Ejigbo	1 Storey	2 Injured

N.B: The last two records were recorded by the authors themselves.

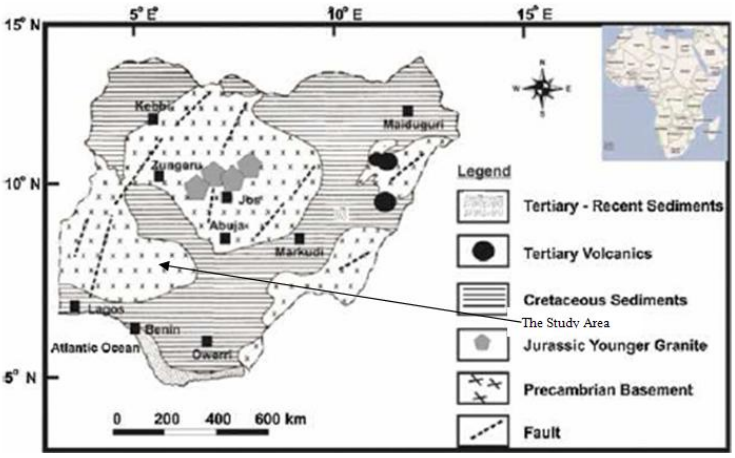


Figure 1: Geological map of Nigeria (after Adepelumi and Fayemi, 2012).

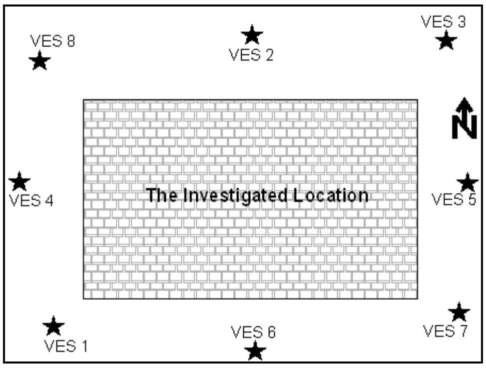


Figure 2a: Location of the VES stations in the study area.

Figure 2b: Location of the VES stations and the patched cracks in the building.

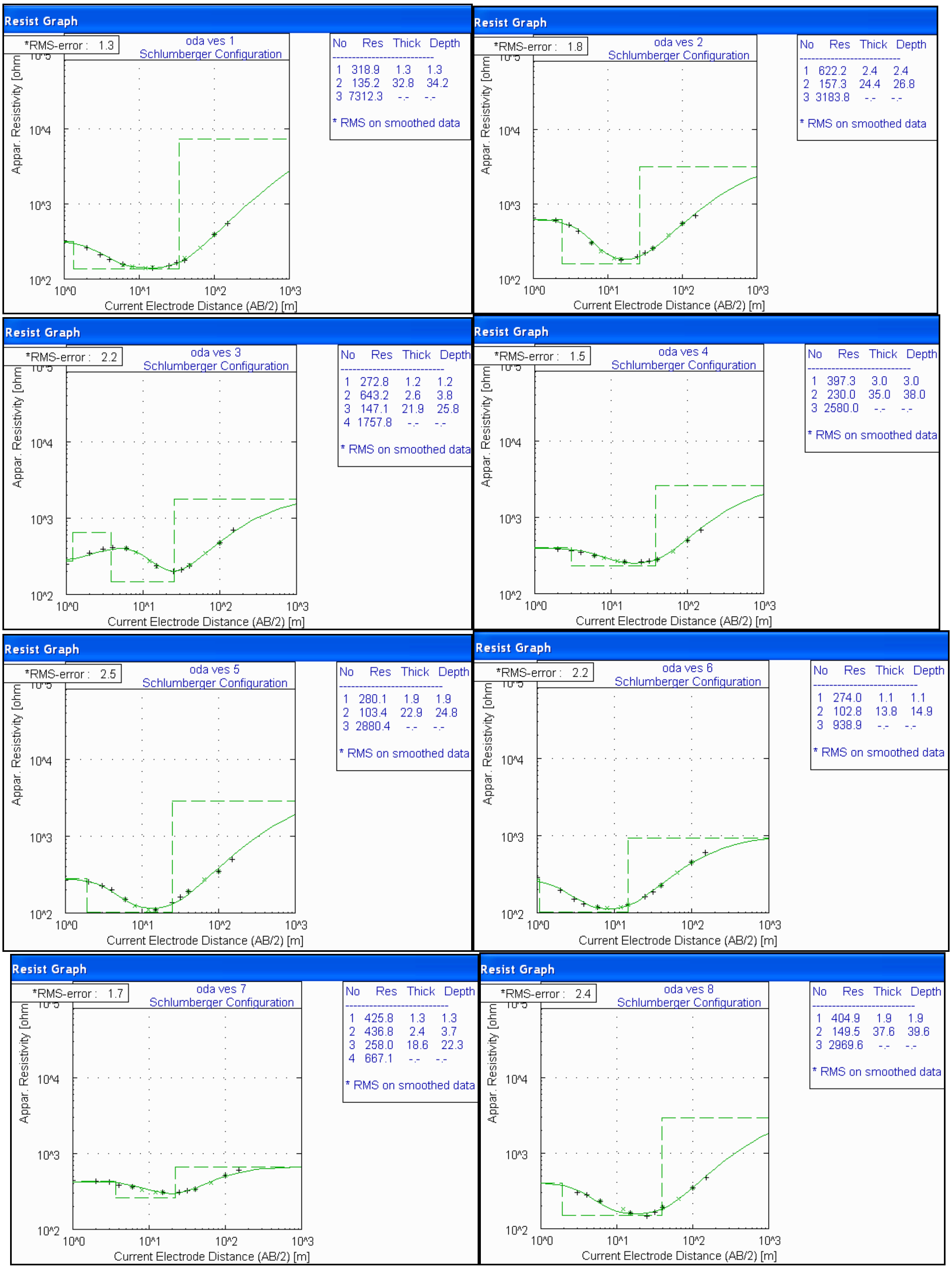
Fugure 2c: The cracks notice at the Eastern fence that separates the building from another house.

Table 2: Summary of the formation of layer parameters.

Location	Layer 1		Layer 2		Layer 3		Layer 4		R.M.S. Error
	ρ_1 (Ωm)	h_1 (m)	ρ_2 (Ωm)	h_2 (m)	ρ_3 (Ωm)	h_3 (m)	ρ_4 (Ωm)	h_4 (m)	
VES 1	318.9	1.3	135.2	32.8	7312.3	-	-	-	1.3
VES 2	622.2	2.4	157.3	24.4	3183.8	-	-	-	1.8
VES 3	272.8	1.2	643.2	2.6	147.1	21.9	1757.8	-	2.2
VES 4	397.3	3.0	230.0	35.0	2580.0	-	-	-	1.5
VES 5	280.1	1.9	103.4	22.9	2880.4	-	-	-	2.5
VES 6	274.0	1.1	102.8	13.8	938.9	-	-	-	2.2
VES 7	425.8	1.3	436.8	2.4	258.0	18.6	667.1	-	1.7
VES 8	404.9	1.9	149.5	37.6	2969.6	-	-	-	2.4

Table 3: Classification of the resistivity sounding curves.

Curve types	Resistivity model	Model frequency	VES Locations
H	$\rho_1 > \rho_2 < \rho_3$	6	1, 2, 4, 5, 6, 8
KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	2	3, 7
Total		8	



Resist Graph

*RMS-error : 1.3

oda ves 1

Schlumberger Configuration

No	Res	Thick	Depth
1	318.9	1.3	1.3
2	135.2	32.8	34.2
3	7312.3	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 1.8

oda ves 2

Schlumberger Configuration

No	Res	Thick	Depth
1	622.2	2.4	2.4
2	157.3	24.4	26.8
3	3183.8	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 2.2

oda ves 3

Schlumberger Configuration

No	Res	Thick	Depth
1	272.8	1.2	1.2
2	643.2	2.6	3.8
3	147.1	21.9	25.8
4	1757.8	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 1.5

oda ves 4

Schlumberger Configuration

No	Res	Thick	Depth
1	397.3	3.0	3.0
2	230.0	35.0	38.0
3	2580.0	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 2.5

oda ves 5

Schlumberger Configuration

No	Res	Thick	Depth
1	280.1	1.9	1.9
2	103.4	22.9	24.8
3	2880.4	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 2.2

oda ves 6

Schlumberger Configuration

No	Res	Thick	Depth
1	274.0	1.1	1.1
2	102.8	13.8	14.9
3	938.9	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 1.7

oda ves 7

Schlumberger Configuration

No	Res	Thick	Depth
1	425.8	1.3	1.3
2	436.8	2.4	3.7
3	258.0	18.6	22.3
4	667.1	-.-	-.-

* RMS on smoothed data

Resist Graph

*RMS-error : 2.4

oda ves 8

Schlumberger Configuration

No	Res	Thick	Depth
1	404.9	1.9	1.9
2	149.5	37.6	39.6
3	2969.6	-.-	-.-

* RMS on smoothed data

Figure 3: The model curves for VES 1 to VES 8.

Table 4: Aquifer potential as a function of the depth to bedrock
(after Sunmonu et al., 2012).

Overburden Thickness (m)	
Range	**Weighting**
< 5	2.5
5 - 10	5
10 - 15	7.5
> 15	10

Table 5: Aquifer potential as a function of the weathered layer resistivity
(after Sunmonu et al., 2012).

Weathered Layer Resistivity (Ωm)		
Range	**Aquifer Characteristics**	**Weighting**
< 20	Clay with limited potential	7.5
21 – 100	Optimum weathering and good groundwater potential	10
101 – 150	Medium conditions and potential	7.5
151 – 300	Little weathering and poor potential	5
> 300	Negligible potential	2.5

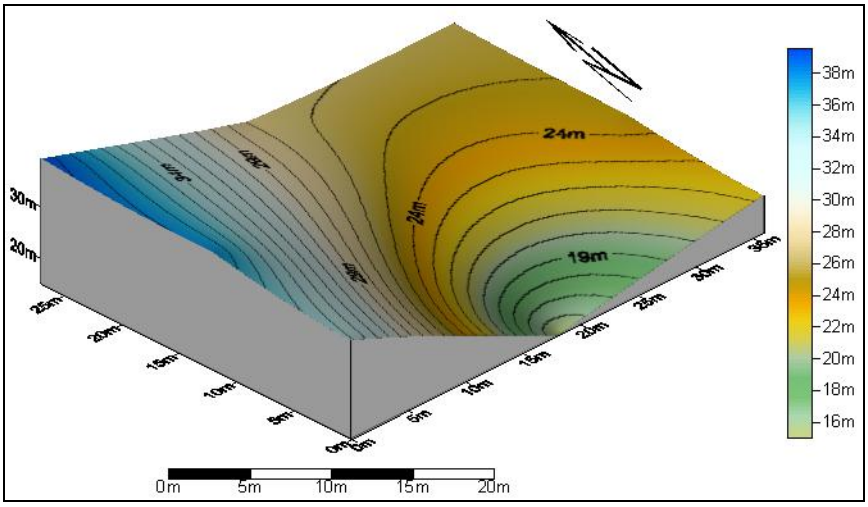


Figure 4: Three-Dimensional plot of overburden thickness in the study area.

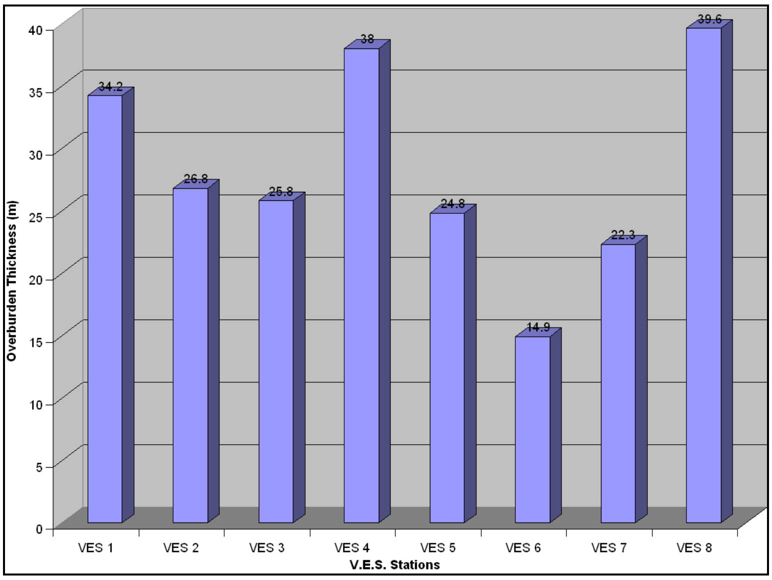


Figure 5: Distribution of the overburden thickness in the study area.

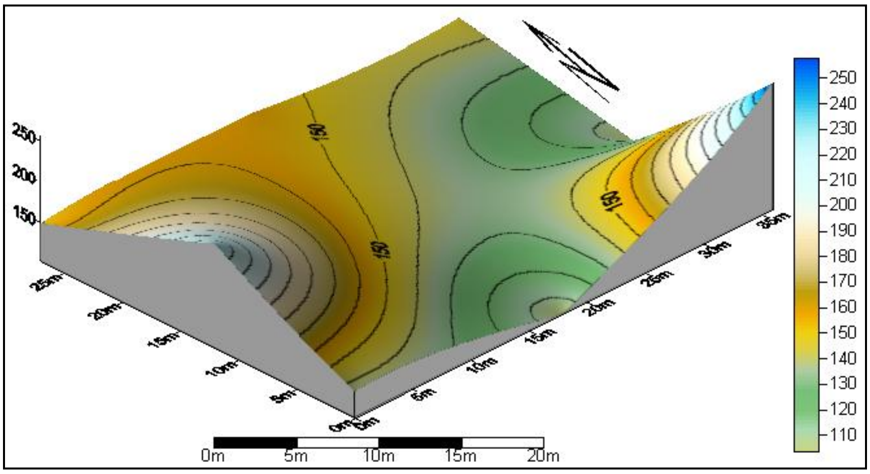


Figure 6: Three-Dimensional plot of weathered layer isoresistivity in the study area.

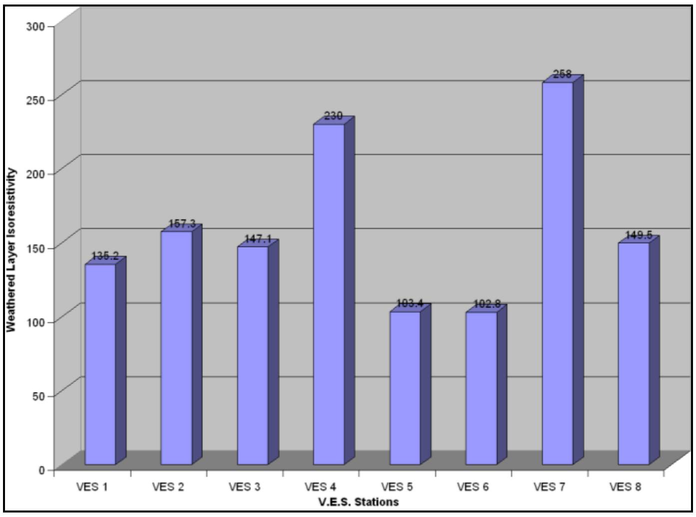


Figure 7: Distribution of the weathered layer isoresistivity in the study area.

Conclusion

The results of the investigation showed that the possible cause of the cracks in the high-rise building constructed along Oda road, Akure is due to building on thick overburden (ranges between 14.9 m and 39.6 m). This overburden is relatively thick for construction of high-rise building without an artificial basement before the foundation is laid. The contractor has his blame because geophysicist should have been invited for geophysical survey before the construction works started. Finally, it was recommended that mega activities like party, playing of heavy acoustic music, manual pounding of yams within the building, use of heavily vibrated machines should be avoided in the building.

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